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Patterns of Forming the Urban Surface Deposited Sediments

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Abstract. The contemporary sedimentation processes participate in the formation of fluxes of the solid substances in an urban area, forming together a source of pollution, transit and depositing media. The patterns of forming the urban surface deposited sediments were determined on the example of Russian metropolis Nizhny Novgorod. Two schemes of the research were implemented in residential districts of the city in the summer field season 2018. The first research design scheme represented a detailed survey of residential quarters of the city. It included a collection of 25 samples of environmental compartments from five residential quarters with multi-storey buildings. The sampling was conducted in various functional landscape parts at the courtyard and facade areas. Each sample was separated into particle size fractions. Chemical and mineral analysis was performed in each granulometric subsample of the collected samples. The second scheme represented the urban geochemical study based on sampling the sediments from local surface depressed zones of microrelief in the city. The 40 samples were collected at the territory of the city on an irregular grid. The sampling was carried out in residential areas in blocks with multi-storey buildings. One sample represented a combined sample of sediments from local surface zones of microrelief by 3-5 localizations from the area of the block. Chemical analysis of the collected samples was conducted. The maximum content of dust (0.002-0.01 mm) 39% was found in soil, while the lower mean dust content was found in the samples of sediment from local surface depressed zones of microrelief (30 %) and in the road deposited sediments (30 %). The mineral composition of soil and sediment in Nizhny Novgorod is represented by quartz sand (approx. 55 %). In the samples of sediments, the minerals' content is basically characteristic for acid and metasomatic rocks. Building materials' content in the sediments reaches up to 20%. The maximum organic matter content was found in fine dust fraction 2-10 microns 21% in soils and 5% on the roads. Differentiation of the mineral content in the samples is observed for the various particle size fractions and different functional parts of the quarters. The highest content of metals of anthropogenic association (such as Pb, Zn and Cu) was found in the dust fraction. The Pb and Zn concentrations in samples of sediment of depressed areas of microrelief and road dust were significantly lower than in the soil.



1. Introduction

The contemporary sedimentation occurring in an urban area influences environmental quality. The complex of sedimentation processes includes natural (such as weathering of material of building constructions and buildings, pavements as a result of freezing and thawing in the presence of moisture; erosion of soils and ground under the influence of surface runoff, dust deposition from the atmosphere) and anthropogenic processes (excavation and other works associated with the development of soil and the violation of the integrity of the coatings, the destruction of soil and road surfaces by passing and parking cars) [1, 2]. Accumulation of the loose material of the sediments increases significantly under bad cleaning of the territory and violation of landscape management techniques.

The formation of loose surface sedimentary material is involved in long-term processes, altering mineral and elemental composition, physicochemical properties of the urban soil [3], changing in volume of the surface stormwater runoff [4], accumulation of the urban surface deposited sediment (USDS) formation (for example road deposited sediment [5]), redistribution of pollutants [6], and forming geochemical barriers.



Figure 1. Urban surface deposited sediments on the passage (a), and in a local surface depressed area of microrelief (b)

The contemporary urban surface deposited sediment represents the upper part of the geological layer in the city (Figure 1). Surface deposited sediment is often used as an indicator in urban geochemical studies [7-9]. The sediment signs the pollution and its pathways in the urban environment [10, 11]. The thickness of sediments varies, the average value is about 5 cm. Time of the existence of the sediment varies from several months to several decades [12]. The content of pollutants in the sediments characterizes the pollution of the territory from which the accumulation of sediment takes place.

In this study, the patterns of forming the urban surface deposited sediments were determined on the example of Russian metropolis Nizhny Novgorod.

2. Materials and methods

2.1. Study area

Nizhny Novgorod lies in the central part of Russia, at the distance about 400 km east of Moscow on the emptying of Oka River into the Volga (56°19'37"N, 44°00'27"E). The total area of the city is 460 km². The hilly relief in the city is represented by the asymmetric right and left banks of the Oka and

Volga. The left bank of the rivers is a lowland plain, and the right banks are high steep slopes with the height difference about 140 m. The climate in the region is humid continental. Winter lasts from late November until late March with a permanent snow cover. Average temperatures range from +19 °C in July to −9 °C in January. Nizhny Novgorod is the fifth-largest city in Russia, with a population of about 1.26x10⁶. Engineering is the leading industry of Nizhny Novgorod's economy and represented by the auto industry, shipbuilding, diesel engines, aircraft manufacture and machine tools.

2.2. Study design

Sampling of environmental compartments involved in the formation of the sediments was conducted by two sample collecting schemes. The first scheme represents a detailed survey of the residential quarters in order to determine the mechanisms of formation and accumulation of the sedimentary material and pollutants. The second scheme is the study of the formation of geochemical conditions of the urban area on the basis of a study of sediments of local surface zones of microrelief.

2.2.1 Sampling scheme 1. Five experimental sites, representing typical quarters were selected in different geographical parts of the city within the street-road network. The quarters should be located in different zones of the lithogenic substratum (if possible), and built up in different decades of the 20th century. The experimental site must include the following functional landscape parts:

- (1) carriageway, (2) pavement and (3) lawn of the facade area of the block,
- (4) playground and green area, (5) organized and unorganized parking lots of the courtyard part of the block.

The samples of environmental compartments were collected at the end of summer. Two samples were collected from the facade area of the quarter and three on the courtyard area:

- road dust (1 sample) and soil (1 sample) from the upper 5-cm layer from the lawn (or the sample of the sediments of local surface depressed zones of microrelief) of the facade area,
- sediments of local surface depressed zones of microrelief from unorganized (1 sample) and organized (1 sample) parking, and soil from a lawn or playground (1 sample) of the courtyard part.

Samples of the sediments of local surface depressed zones of microrelief and soil were collected by a scoop. The sample was combined from samples collected from 3-5 localizations in a given landscape area.

2.2.2 Sampling scheme 2. The 40 samples the sediments of local surface zones of microrelief were collected on an irregular grid in the city. The sampling was carried out in residential blocks with multi-storey buildings. One sample was combined from samples of sediments from 3-5 local surface zones of microrelief by the territory of the block. The sample weight was 1-1.5 kg. A short description of the sampling site was conducted, containing information on the formation of the sediments, their thickness, area of the quarter, the percentage of green areas, sidewalks, parking areas on the territory of the quarter, the quality of cleaning, the planning of the territory and construction works.

2.3. Granulometric analysis

Particle size fractionation for the samples was performed by decantation and wet sieving. The decantation allowed obtaining the solutions with particle size fractions 0.002–0.01 and 0.01–0.05 mm (Test Method WA 115.1-2017). The solid materials of 0.002–0.01 mm and 0.01–0.05 mm size were separated by vacuum filtering of the solutions through cellulose filters with respective pore sizes. The fractions > 1, 0.25–1 mm, 0.1–0.25 mm, and 0.05–0.1 mm were wet sieved through a cascade of filters with cell diameter 1 mm, 0.25 mm, and 0.01 mm correspondently. The solid material separated into particle size fractions was dried, the mass of fractions 0.002–0.01, 0.01–0.05, 0.05–0.1, 0.1–0.25, 0.25–1, and > 1 mm were measured and mass portions of the fractions were calculated.

2.4. Mineral analysis

The mineral composition of the granulometric subsamples was determined by the X-ray phase and thermal analysis in the centre of collective use "Geoanalyst" in the Institute of Geology and Geochemistry named after the academician A. N. Zavaritsky UB RAS. The X-ray phase analysis was performed on an XRD-7000 X-ray diffractometer. The thermal analysis was carried out on the Diamond TG / DTA derivatograph.

2.5. Chemical analysis

The total content of elements in the collected samples and granulometric subsamples was determined by inductively coupled plasma mass spectrometry technique using ELAN 9000 mass spectrometer from Perkin Elmer (USA) [13].

2.6. Landscape analysis

The field landscape description represents an examination of the functional parts of the quarter. The questionnaire was filled for each functional part of the landscape (outside and inside the courtyard) containing the information on:

- type of coat (asphalt, gravel, etc.);
- violation of coverage (as a percentage of the functional part area);
- the general technical conditions of the functional part;
- organized or unorganized type of car parking;
- the number of parking spaces and cars parked;
- cleaning the functional part;
- repair and construction works at the functional part of the landscape and the type of these works;
- a difference in heights;
- the presence of surface depressed zones of microrelief;
- sources of surface dirt and mud sediment (the internal sources provide the formation of dirt in the study area, the external – transfer the mud from neighbouring areas).

Each functional area was photographed.

3. Results and discussions

According to scheme 1, 25 samples of environmental compartments were collected in Nizhny Novgorod in 2018, and 40 samples were collected according to scheme 2. The granulometric analysis was carried out for 25 samples, collected according to scheme 1, and in 10 random samples from sample population taken according to scheme 2. Each sample was separated into 6 subsamples. Totally, 210 granulometric subsamples were obtained. The mineral composition was determined in 99 granulometric subsamples, and elemental composition was measured in 101 subsamples. The results of granulometric, mineral, and chemical analyses of the collected samples in Nizhny Novgorod are summarized in Table 1.

A heterogeneous redistribution of the content was found for typomorphic macroelements, typomorphic microelements, metals of anthropogenic geochemical association, dust material between the connected functional areas of the urban quarter within the residential area of Nizhny Novgorod.

The maximum content of dust fraction (0.002-0.1 mm) was found in soil (in an average 39% of the sample mass). The mass portion of dust reduces to 30% and 16% in sediments of local surface depressed zones of microrelief and in the road dust, respectively. 70-80% of the dust fraction material is represented by particles of 0.05-0.1 mm size.

The mineral composition of soil and sediments in Nizhny Novgorod is represented by quartz (quartz sand), minerals of acid (granite) and metasomatic (chlorite, amphibole, etc.) rocks, particles of building materials (dolomite, calcite, and partially quartz), and organic matter. Single slag and spherical particles were also found in the surface sediments.

The differences in mineral content of the studied samples are characteristic for the different particle size fractions and for the different functional parts of the landscape. Quartz sand prevails in soils on lawns and sediments in courtyard areas. The average content of quartz in dust fraction in soil and sediment samples varies in the range of 54-59 % by weight. Quartz content reaches 80% in coarser sediment fractions (0.1-1 mm). It should be noted that the floodplain terraces on which Nizhny Novgorod is located are formed by alluvial deposits, mainly quartz sand. The maximum content of minerals attributed to building material mixtures (the total content of dolomite and calcite in the dust fraction is 20%) was found in samples of road deposited sediments. The content of building material mixtures in soil and sediments of local surface zones of microlandscape samples was 6% and 13% respectively. The content of minerals of metasomatic group prevails in the dust fraction. The minerals composing granite are uniformly distributed over the particle size fractions and in the functional parts of quarters; and correspond to 40% of the composition of the sedimentary material (including partial quartz).

There are significant differences in the content of organic matter in the samples. The maximum content was found in the dust fraction in soil samples - 3%, with a decrease to 0.8% in road deposited sediments. At the same time, the content of organic matter reaches 21% in soils and 5% on the roads in the fraction of 0.002-0.01 mm.

Micro- and macroelements of the typomorphic association are distributed according to the mineral composition of the granulometric fractions and types of the collected environmental compartments. The Fe, Al, V, Sn and other trace elements' concentrations decrease with an increase of quartz (SiO₂) content in the particle size subsamples: from 20 g/kg to 4 g/kg for Fe, from 34 g/kg to 8 g/kg for Al, from 2.6 to 0.4 g/kg for Ti in dust and coarser fractions respectively.

Concentrations of separate typomorphic macro- and microelements are associated with the functional parts zones of the landscape. Concentrations of several elements of typomorphic association in dust decreases significantly in the sequence of environmental compartments 'lawn soil – sediments of local surface depressed zone of microlandscape – road deposited sediments': Al (41–34–27 g/kg), Ru (57–43–30 mg/kg), Th (5.8–4.6–3.3 mg/kg), U (4.9–1.7–1.5 mg/kg) and W (3.5–5.4–6.3 mg/kg).

The accumulation of metals of the anthropogenic association was found in dust fraction. The maximum average Pb concentration of 79 mg/kg was found in the fraction of 0.002-0.01 mm, which is about four times higher than Pb concentration corresponding to the initial geochemical baseline conditions for Nizhny Novgorod. The Pb concentration in samples of sediments of local surface depressed zones of landscape and in road deposited sediments is about 1.5 times lower than in soil. Zinc has a similar distribution between the landscape functional parts and over the size fractions. Copper shows the maximum average concentration of 140 mg/kg in the road deposited sediments, and minimum 113 mg/kg in soil.

A significant part of the residential quarters is represented by passages, driveways and parking lots including unorganized ones. The zone related to automobile transport includes up to 50% of the residential areas of the city. This functional part of the urban residential area is densely filled with parked cars. Approx. 130-160 m² of the area of residential quarter accounts for one parking space. Thus the capacity of the existing road transport infrastructure of the courtyards and the surrounding

external space has been exhausted. A significant number of cars are regularly parked in inappropriate places. In Nizhny Novgorod, 22% of the courtyards area represents such “parking spaces”.

A significant part of the residential areas of the city does not have a coating that prevents weathering and abrasion of the material of the surface: areas with destroyed asphalt coating, and lawns and green areas with low grass cover. In total, the area with undisturbed cover is 15% total area of the residential neighbourhoods in Nizhny Novgorod. A significant part of the area without cover refers to lawns, sports and playgrounds with low grass cover (average coverage 54%). In general, taking into account the carriageway of streets, courtyard passages and green areas with low grass cover, dust source surfaces occupy up to 68% of the area of residential districts in Nizhny Novgorod.

There is the formation of dirt and dusting during the processes of the ground excavation and construction works in the residential areas due to the following reasons: storing the excavated soil in dumps, placing bulk building materials in heaps, absence of reclamation of sites. Pollution of the urban environment with dust and mud material is a regular phenomenon during excavation or construction works.

Part of the surveyed landscape areas is polluted with solid sedimentary material transferred from neighbouring landscape parts with impaired or absent asphalt or lawn cover. Sloppy conditions and destroyed curbs cause the additional lateral transfer of the sedimentary material.

Table 1. The results of granulometric, mineral, and chemical analyses of samples collected in Nizhny Novgorod

Parameter	Sampling scheme 1				Sampling scheme 2
	Soil and ground	USDS	RDS	all	USDS
Particle size composition, mass portion					
-	Dust (0.002-0.1 mm)			Sand (0.1-1 mm)	-
-	0.40	0.30	0.16	0.34	-
Mineral content, mass %					
Quartz	59	54	54	80.9	-
Dolomite	5	10	15	2.6	-
Calcite	1	3	5	1.0	-
Plagioclase	11	11	8	6.3	-
Microcline	7	8	5	7.3	-
Orthoclase	5	4	2.7	2.5	-
Chlorite	4	4	4	0.5	-
Amphibole	0.6	1.4	0.8	0.0	-
Hydromica	6	4	4	0.1	-
Organic matter	3.0	2.3	1.3	0.0	-
Total elements' concentrations, mg/kg					
Al, g/kg	41	34	28	8	17
Fe, g/kg	22	20	21	4	14
Ti	2864	2596	2565	436.7	1133
Ba	420	368	306	129.3	218
Mn	536	490	448	100.6	313
Cr	118	94	102	28.3	332
V	65	66	70	12.2	31
Rb	57	43	30	10.6	24.6
Ni	49	47	50	9.1	30.5
As	11	9	12	3.9	8
Sn	10	6.5	7.0	1.3	2

Co	9	10	9	1.9	5.2
Th	5.8	4.6	3.3	0.7	2.3
U	4.9	1.7	1.5	0.4	1.14
W	3.5	5.4	6.3	0.4	3.6
Cd	2.1	3.2	2.7	0.6	0.8
Mo	1.8	1.1	1.6	0.3	1.4
Sb	1.4	1.6	1.8	0.2	0.88
Zn	490	338	348	55.2	147
Cu	113	135	140	27.6	32.6
Pb	69	48	44	22.1	20.7

4. Conclusions

Thus, the patterns of redistribution of pollutants and dust in depositing media and in various functional parts of the urban residential quarters have been identified. It is shown that contemporary sedimentation processes in an urban environment play a significant role in the functioning of the cascade landscape-geochemical system in a residential area. Sedimentation processes are involved in the formation of fluxes of substances in an urban environment at all stages, being both a source of pollution and transit and depositing media. In addition, sediments as a component of the urban landscape perform a geo-indicator function along with such objects as the atmospheric air, snow, soil, and others. Analysis of the trace elements by granulometric fractions showed the main mechanisms of the accumulation of pollutants. A landscape description has allowed characterizing of the conditions for the formation of sediments at the territories of the selected residential quarters. The analysis of the questionnaires allows obtaining the landscape features associated with the redistribution of sediment material on the territory of the block between different parts of the microlandscape, and the ways of the sediment transport. The main reasons for forming the urban surface sediments are the bad landscape infrastructure facilities in the courtyard spaces, as well as bad management and cleaning in most of the courtyards.

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